alone are useful. Hence it follows, that if we have, at a certain step of the process, cos $(2\,V + 3\,T)$, its coefficient must be $e^2\,e'^3$, and this may be written $e^2\,e'^3$ cos $(2 + 3)$ without fear of mistake; and this, when combined with such a term as cos $(11\,V - 11\,T)$, will produce $e^2\,e'^3$ cos $(13 - 8)$. This mode of writing and operating is also a great saving of labour; for V and T consist of the mean motions, with several constant terms added or subtracted.

The author states that he has paid great attention to ensuring the accuracy of the work; having gone through the calculation by two different methods, and compared the values thus obtained, both in several intermediate steps, and in the final results.

We regard this paper as the first specific improvement in the solar tables made by an Englishman since the time of Halley, as valuable from the care which the author has employed in the numerical calculations, as well as for the sagacity he has displayed in the detection of an inequality so small, and of so large period; and we recommend its insertion in the Philosophical Transactions.

(Signed) W. WHEWELL.
J. W. LUBBOCK.

April 5, 1832.

DAVIES GILBERT, Esq., M.A. Vice-President, in the Chair.

Marshall Hall, M.D., Archibald John Stephens, Esq., Sir William Russell, Bart., M.D., Sir David Barry, Knt., M.D., and Charles Boileau Elliott, Esq., were elected Fellows of this Society.

The following Report, drawn up by Samuel Hunter Christie, Esq., M.A. F.R.S., and John Bostock, M.D. V.P.R.S., on Mr. Faraday's paper, read before the Royal Society on December 15, 1831, and entitled "Experimental Researches in Electricity," was read.

Report.

In the first section of this paper, the author considers the induction of electricity in motion.

Shortly after the discovery by Oersted of the influence of electricity in motion on a magnetic needle, it was almost simultaneously discovered by Arago, Davy, and Seebeck, that iron became magnetic by induction from the connecting wire of a voltaic battery, or the passage of an electric current; but though the effects at first observed were afterwards greatly increased by peculiar arrangements, induction was in all cases restricted to iron. Arago's beautiful experiments on magnetic needles vibrating within metallic rings, and on the mutual action of all metals and magnets, when either is in motion, are undoubtedly instances of a peculiar magnetic induction in other metals than iron; but the very doubtful experiment of Ampère can scarcely be adduced as one. The singular results obtained by MM. Marianini, De la Rive, and Von Beek, referred to by our author, are probably due to electric induction. But none of these

can be considered as having originated the discoveries described in the present paper, excepting so far as all new views originate in the contemplation of results previously obtained.

In this section of his paper the author shows that a peculiar state is induced in a copper wire which is in the immediate neighbourhood of another, through which an electric current passes, that is, which forms the connecting wire in a voltaic circuit. This state of the wire was manifested by its action on a magnetised needle, and by the induction of magnetism in steel wire submitted to its action.

Two copper wires, each more than 200 feet in length, were wound in the same direction round a large block of wood, the coils of the one being interposed between those of the other, and metallic contact everywhere prevented. The ends of one wire were connected with a galvanometer, and with the ends of the other, contact could be made or broken with a battery of one hundred and twenty pairs of plates. On the contact with the battery being made, the needle of the galvanometer was invariably impelled in one direction, and on the interruption of the contact, it was always impelled in the contrary. After the first impulse on the completion of the voltaic circuit, the needle resumed its natural position, no permanent deflection whatever occurring during the time that this circuit remained complete.

On substituting a helix of copper wire formed round a glass tube for the galvanometer; introducing a steel needle; making contact, as before, between the battery and the inducing wire; and then withdrawing the needle, previously to breaking the battery contact, it was found to be magnetised. If the contact was first made; a needle introduced in the tube; the contact broken; the needle on being withdrawn was found to be magnetised to the same degree nearly as the first, but the poles at the corresponding ends were of the contrary kind.

If the circuit between the wire under induction and the galvanometer was not complete when the contact with the battery was made, then no effect on the needle was observable either on completing or again breaking the first circuit. But the battery communication being *first* made, and *then* the wire under induction connected with the helix containing the needle, on interrupting the battery circuit, the needle was magnetised. These last facts, in a theoretical point of view, are most important: they prove that on completion of the voltaic circuit, the state of the wire under induction undergoes a double change, the one momentary, the other permanent so long as the voltaic circuit remains complete, and only exhibiting a momentary action on the interruption of that circuit.

From the experiments detailed in this section, the author concludes, that currents of voltaic electricity produce, by induction, currents (but which are only momentary) parallel to or tending to parallelism with the inducing currents; that the induced current, by the first action of the inducing current, is in the contrary direction to, and by its cessation in the same direction as, that of the inducing current.

The author next introduced iron into his arrangement, by which means a double induction took place, the iron itself becoming magnetic by induction, in the first instance, and electricity being induced in the copper wire from the magnetised iron, in the second. The effects were here of precisely the same character as before, but greatly increased. By this arrangement unequivocal evidence of electricity in the wire under induction was obtained; for not only was the needle in the galvanometer violently affected, but a minute spark could be perceived on using charcoal at the ends of that wire.

On dispensing altogether with the voltaic arrangement, and substituting for the electro-magnet a cylinder of soft iron, rendered magnetic by contact with two bar magnets, or a common cylindrical magnet of steel, similar results were still obtained. The arrangement and the effects were simply these: several helices of copper wire were formed, in the same direction, round a hollow cylinder of pasteboard, metallic contact being prevented between the contiguous coils: of these, either the *alternate ends* were united, to form *one* long helix, or *all* the corresponding ends to form a *compound* helix; and within the pasteboard cylinder, a cylinder of soft iron was introduced: on the ends of this cylinder being brought into contact with the poles of two bar magnets, united at the other ends so as to resemble a horse-shoe magnet, the needle of the galvanometer was impelled in one direction, and on the contact being broken, in the contrary. Similar effects were produced by simply introducing a cylindrical steel magnet into the hollow cylinder over which the copper wire was wound. The effects were strikingly increased, but were still of precisely the same character, when Knight's large compound magnet, belonging to the Royal Society, was substituted for the bar magnets. Here, the mere approximation to the magnet, of the compound helix, whether containing the cylinder of soft iron or not, was sufficient to impel the needle in one direction, and its recess from the magnet, to give a contrary impulse. But even here, the effects were purely impulsive, the needle invariably returning to its undisturbed direction, when the contact was continued.

As in the voltaic arrangement, a small voltaic apparatus, sufficient to deflect the needle of the galvanometer 30° or 40°, being introduced between the galvanometer and the helix under induction, produced no effect on the impulses given to the needle, on making and breaking contact of the iron cylinder with the magnet: nor did the power of this arrangement appear to be affected after making the contact or after breaking it.

Although all attempts to obtain chemical effects or a spark in this case failed, yet we agree with the author that these experiments prove the production of electricity by ordinary magnetism, and think the reasons which he adduces for its want of energy satisfactory *.

* Since this report was written, a brilliant electric spark has been obtained by Mr. Faraday and Mr. Christie with this magnet, by the very means which, at this time, failed, in consequence of two contacts not taking place at the same instant, on which circumstance the success of the experiment appears entirely to depend.

This discovery has therefore supplied the link in the chain of connexion between electricity and magnetism, which has been wanting since Oersted's discovery. That the electricity developed acts in a peculiar manner, so far from diminishing the interest attached to the discovery, adds greatly to its value.

After the detail of these perfectly original and highly interesting experiments, the author considers the peculiar electric state of the wire when subjected either to volta-electric or magneto-electric induction. This state he terms the electro-tonic state.

Unlike the induction from electricity of tension or the ordinary induction from a magnet, this state of the wire is not analogous to that of the inducing wire; for whatever may be the permanent state of the wire under induction while the voltaic circuit is complete, or the magnetic contact is unbroken, so long as either of these continues, there is no evidence of any change having taken place in it, and its change of state is only rendered manifest at the instant of interrupting the circuit or the contact, and at that of again renewing them; impulsive forces being brought into action at either instant, but in contrary directions in the two cases.

The author observes, that this peculiar condition shows no known electrical effects whilst it continues, nor has he yet been able to discover any peculiar powers possessed by matter whilst retained in this state; that no re-action is shown by attractive or repulsive powers; that no retarding or accelerating power is exerted upon electric currents passing through metal in the electro-tonic state, that is, the conducting power is not altered by it; that all metals take on this peculiar state; that the electro-tonic state is altogether the effect of the induction excited, and ceases with the inductive power; that this state appears to be *instantly* assumed, the force brought into action at the instant of its assumption being merely impulsive.

The author considers that the current of electricity which induces the electro-tonic state in a neighbouring wire, probably induces that state also in its own wire, and that this may be the case with fluids and all other conductors; and concludes that if it be so, it must influence voltaic decomposition and the transference of the elements to the poles. Should facts be found to accord with these views, we consider the author fully justified in his anticipations of the importance of his discovery as applicable to the decomposition of matter, and we certainly feel that the discovery could not have been made by any one more likely to decide this question, or more able to avail himself of a new principle of decomposition when discovered.

In the series of actions proceeding from the voltaic battery which this discovery exhibits to us, a very curious succession is observable. Volta-electricity passes along the connecting wire of the battery, electro-magnetism at right angles to it. By this means the cylinder of soft iron, within the helix into which the connecting wire is formed, becomes a magnet. If the poles of the magnet be joined by an iron bar, ordinary magnetism passes along this bar, but magneto-electricity is induced at right angles to it in a helix wound round it. And again, magneto-electricity is propelled along the wire, and magnetism

is induced in a steel bar at right angles. This bar may again induce magneto-electricity in a wire at right angles to it, by which another bar may become magnetic; and so on, showing a repetition of similar powers successively brought into action, but their efficiency at each step greatly diminished.

The effects hitherto described were due to a momentary action: in order to obtain continuous action the author applied the principle of circular motion. For this purpose a thick copper disc was made to revolve near the magnet, so that a portion near its edge passed between the ends of two bars of iron which concentrated and approximated the poles. The edge and a portion round the centre of the disc were well amalgamated: an amalgamated conductor was applied to the edge of the disc near the poles, and with this, one end of the wire of the galvanometer was connected, the other end being connected with the centre of the disc. While the disc revolved, the needle of the galvanometer was permanently deflected at least 45° in one direction; and when the motion of the disc was reversed, the permanent deflection was in the opposite direction.

When the disc revolved horizontally in the direction of the sun's daily motion, the unmarked pole being beneath the disc and the marked pole above, it appeared, by the indications of the galvanometer, that positive electricity was collected at the edge of the disc nearest to the poles: if the marked pole was below and the unmarked pole above, then negative electricity was collected at that part of the disc: and if in either case the direction of the motion was reversed, the nature of the electricity collected at the same place was also reversed.

The experiment being made in a still more simple form, by passing a plate of copper longitudinally between the poles of the magnet, it appeared that positive electricity was collected on one edge of the plate, and negative on the opposite; and if the plate was passed in the contrary direction, then the electricities on the edges were reversed.

When a wire was passed laterally between the poles, similar results were obtained.

The law according to which the electricity excited depends upon the pole of the magnet near which a wire moves, and the direction of its motion, although not so expressed by the author, appears to be this: Let the wire revolve parallel to itself about a bar magnet, so that its centre coincides with any curve;—for example, (in order to mark more readily the points where the direction of the current of electricity changes,) with an ellipse, the major axis of which coincides with the axis of the magnet, and the minor axis passes through its centre; let the wire be inclined at any angle to the plane of the ellipse, which in the first instance we will suppose to be horizontal, and that the marked end of the magnet is pointing north; and let the wire move parallel to itself in the direction of the sun's daily motion; then while the wire revolves from the *western* extremity of the axis minor round the *marked* pole to the *eastern* extremity, the electric current will be from the end of the wire *below* to the end *above* the orbit:

while it is revolving from the *eastern* extremity round the *unmarked* pole to the *western* extremity of the axis minor, the current of electricity will be from the upper to the lower end of the wire; and whatever position the plane in which the wire revolves may take by revolving about the axis of the magnet, or whatever may be the position of this axis, still the current of electricity will be from the end of the wire in the same position, relatively to the plane of revolution, as before. If the direction of the motion be reversed, the direction of the current will likewise be reversed.

It would follow from this, that if two wires parallel to each other, on opposite sides of a bar magnet, and perpendicular to its axis, be moved along the sides of the magnet in the same direction, the currents of electricity in them will be in opposite directions; and hence we may draw this important conclusion,—that there must be some internal arrangement in a magnet, whether of currents or of particles, which renders the same absolute motion, a motion in contrary directions relatively to such arrangement on the opposite sides of the magnet.

From all these experiments the author concludes, that when a piece of metal (and the same may be true of all conducting matter,) is passed either before a single pole, or between the opposite poles of a magnet, electric currents are produced across the metal, transverse to the direction of motion; and which therefore in M. Arago's experiments approximate towards the direction of radii. Assuming the existence of these currents, he satisfactorily accounts for the phænomena observed in these experiments and in those by Mr. Babbage and Sir John Herschel. Thus, the disc revolving in the direction of the sun's daily motion beneath the marked pole of a magnet, currents of positive electricity set from the central part towards the circumference near the pole, and the action of these currents is to move the pole also in the direction of the sun's motion; so that the magnet, if at liberty to revolve, will move in the same direction as the disc.

Electric currents similar to those produced by passing copper between the magnetic poles, were produced by iron, zinc, tin, lead, mercury, and all the metals tried. The carbon deposited in the coal-gas retorts also produced the current, but ordinary charcoal did not; nor could any sensible effects be produced with brine, sulphuric acid, or saline solutions. Although the author succeeded in obtaining a continuous current of electricity by means of the revolving disc, yet he was not able, by this means, to produce any sensation upon the tongue, to heat fine platina wire, to produce a spark with charcoal, to convulse the limbs of a frog, or to produce any chemical effects. That he should have failed in obtaining these most striking effects of electricity, we attribute to the feebleness of the electricity excited, and feel assured that by adopting means greatly to increase the intensity, all these effects will result from the electricity derived from ordinary magnetism.

The facts contained in this paper of Mr. Faraday's, and the con-

clusions which he draws from them are so important, that we feel we should not have done justice to the communication, had we not given an abstract of the whole, at the same time that we stated our opinion of its value. Had the author's discovery consisted alone of the simple fact, that steel may be magnetised by a distant magnet, in a manner similar to that employed with the voltaic battery, we should have considered it of the highest importance in the inquiry concerning the connexion between magnetism and electricity; but when we see permanent effects which, hitherto, have only been derived from electricity, now derived from the common magnet, by calling in the aid of motion, showing clearly that electricity can thus be excited; and find that the laws which govern the phænomena are established, we cannot but entertain hopes that a door has been opened through which may at length be discovered the precise distinction between two agents which in many respects so greatly resemble each other in their effects and in their laws of acting. Such being our opinion of the results obtained by Mr. Faraday, we can have no hesitation in recommending most strongly the publication of his paper in the Transactions of the Royal Society.

(Signed) S. H. Christie.
J. Bostock.

Dr. Davy's Paper on the Torpedo, was then read in continuation.

April 12, 1832.

HIS ROYAL HIGHNESS THE DUKE OF SUSSEX, K.G.
President, in the Chair.

The reading of Dr. Davy's Paper, entitled, "An Account of some experiments and observations on the Torpedo," was resumed and concluded.

The late Sir Humphry Davy gave an account, in a paper published in the Philosophical Transactions for 1829, of some experiments which he made on the Torpedo, with the view of ascertaining how far its electricity is analogous to that of the voltaic, or other galvanic batteries; but the results he obtained were altogether of a negative kind. He was prevented by the declining state of his health from prosecuting this inquiry, which he was still ardently bent upon completing, and which he requested his brother would carry on after his death. The author, accordingly, when at Malta, being in a favourable situation for obtaining living torpedos, made the series of experiments which are related in the present paper. They entirely confirm those of Mr. Walsh made in 1772, and which established the resemblance of the agency exerted by this fish to common electricity; and they also prove that, like voltaic electricity, it has the power of giving magnetic polarity to steel, of deflecting the magnetic needle, and also of effecting certain chemical changes in fluids subjected to its action. Needles perfectly free from magnetism were introduced within a spiral coil of copper wire, containing about 180 convolutions; the whole coil being an inch and a half long and one